# IERS conventions for Handling Atmospheric Loading

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Temporal variations in the geographic distribution of atmospheric mass load the Earth and deform its surface. For example, pressure variations on the order of 20 HPa (and even larger) at mid-latitudes, are observed in synoptic pressure systems with length scales for 1000-2000 km and periods of approximately two weeks. Seasonal pressure changes due to air mass movements between the continents and oceans can have amplitudes of up to 10 HPa in particular over the large land masses of the Northern Hemisphere. At the interannual periods, basin-wide air pressure signals with amplitudes of several HPa also contribute to the spectrum of the loading signal.

Other surface loads due to changes in snow and ice cover, soil moisture and groundwater, as well as ocean-bottom pressure also contribute to surface displacements. For example, at seasonal time scales, it is expected that the contribution of hydrological loads to surface displacements exceeds the one from air pressure (Blewitt *et al.*, 2001). However, while the atmospheric load is fairly well known from global air pressure data sets, no suffcient models for ocean bottom pressure, snow and soil moisture exists at this time. Therefore, in the following, focus is on atmospheric loading. However, the discussion applies also to any other surface load.

Theoretical studies by Rabbel and Zschau (1985), Rabbel and Schuh (1986), vanDam and Wahr (1987), and Manabe *et al.* (1991) demonstrate that vertical crustal displacements of up to 25 $mm$ are possible at mid-latitude stations due to synoptic pressure systems. Annual signals in the vertical are on the order of 1-2 mm but maximum signals of more than 3 mm are possible over large parts of Asia, Antarctica, Australia and Greenland (Mangarotti *et al.*, 2001; Dong *et al.*, 2002). Pressure loading effects are larger at higher latitude sites due to the more intensive weather systems (larger in amplitude and more spatially coherent) found there. Effects are smaller at mid-latitude sites and at locations within 500 km of the sea or ocean due to the inverted barometer response of the ocean. In all cases, horizontal crustal deformations are about one-third the amplitude of the vertical effects.

Two basic methods for computing atmospheric loading corrections to geodetic data have been applied so far: 1) using geophysical models or simple approximations derived from these models and 2) using empirical models based on site-dependent data.

The standard geophysical model approach is based on the estimation of atmospheric loading effects (vertical and horizontal deformations, gravity, tilt and strain) via the convo-

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lution of Green's functions with a global surface pressure field. The geophysical approach is analogous to methods used to calculate ocean tidal loading effects. However, due to the continuous spectrum of the atmospheric pressure variations, the compution of the atmospheric loading signal must be carried out in the time domain. The major advantage of the geophysical model approach is that loading effects can be computed in a standardized way for any point on the Earth's surface more or less instantaneously. The geophysical approach currently suffers from a number of problems including: the requirement of a global pressure data set, a minimum of 24 hours in time delay in the availability of the global pressure data set, limitations of the pressure data itself (low temporal and spatial resolution), uncertainties in the Green's functions and uncertainties in the ocean response model.

In the empirical approach, site-dependent pressure loading effects are computed by determining the fit of local pressure variations to the geodetic observations of the vertical crustal motion. This approach is likely to produce better results (than the geophysical approach) for a given site but has a number of drawbacks as well. 1.) Geodetic observations have to be available for a certain period of time before a reliable regression coeffcient can be determined; this period of time may be as large as serveral years. 2.) The regression coefficients cannot be extraploated to a new site (for which no data exist); 4.) The regression coefficient has been observed to change with time and with observing technique; 4.) Regression coefficients at coastal sites are time dependent due to interannual changes in the regional weather pattern (H.-P. Plag, personal communication, 2002); 5.) The regession coefficient can only be used for vertical crustal motions; and 6.) It is uncertain that other pressure correlated geodetic signals are not being 'absorbed' into the regression coefficient determination. So while this approach would lower the scatter on a given geodetic time series the most, one would always be uncertain whether only atmospheric loading effects were being removed with the correlation coefficient.

In a hybrid method, regression coefficients determined from a geophysical model instead of geodetic observations could be used to operationally correct observed vertical position determinations from local air pressure alone. The vertical deformation caused by the change in pressure, in this case, can then be given in terms of a local pressure anomaly. The regression coefficients can be determined by fitting local pressure to the vertical deformation predicted by the geophysical model. Regression coefficients determined in this manner would still suffer from both the uncertainty in the Green's function and the quality of the air pressure data.

In February 2002, the Special Bureau on Loading (SBL) was established within the IERS. The charge of the SBL is to promote, stimulate and coordinate work and progress towards a service providing information on Earth surface deformation due to surface mass loading, including the atmosphere, ocean and continental hydrosphere. In establishing the SBL the IERS is recommending that the convention for computing atmospheric loading corrections will be based on the geophysical model approach.

At the 2002 IERS Meeting in Munich, the IERS adopted the convention that corrections for surface load variations including the atmosphere should be determined using the geophysical model approach. Further, these corrections should be obtained from the IERS SBL. The point of this recommendation is to insure that comparisons of geodetic time series between different observing techniques or within the same technique but at different times and locations have a consistent atmospheric pressure loading (and later also non-tidal ocean and continental hydrological loading) correction applied.

The ultimate goal of the SBL is to provide in near real-time a consistent global solution data set, describing at the surface, deformation due to all surface loads (including atmospheric pressure variations) in reference frames relevant for direct comparison with geodetic observing techniques. The SBL will provide global gridded solutions of 3-d displacements and time series of displacements for all IERS sites. Time series will be determined from 1985 to the present. Displacements will be determined for both the European Center for Medium Range Weather Forecasts and the National Center for Environmental Prediction operational pressure data sets for the inverted barometer and the non-inverted barometer ocean models. For more information see: http://www.gdiv.statkart.no/sbl.

Regression coefficients based on a geophysical model are already available for a number of VLBI sites through the SBL web page and the IERS convention's web page `ftp://maia.usno.navy.mil/conv2000/chapter7/atmospheric.regr`. The regression coefficients were computed using 18 years of the NCEP Reanalysis Data (1 Jan. 1980 to 31 Dec. 1997). The data are 6 hourly values of surface pressure given on a $2.5° \times 2.5°$ global grid. Vertical crustal motions at a particular site are modeled by convolving Farrell's (1972) Greens functions for a Gutenberg-Bullen A Earth model. The ocean was assumed to be inverse barometric for the calculations. The regression results (mm/mbar) are determined via a linear regression between the modeled crustal displacements and the local surface pressure determined from the NCEP data set. An inverted barometer model was used in determining the ocean's response to pressure.

For more information on atmospheric pressure loading and geodetic time series, see the references listed in the extended bibliography.

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